APPLICATION OF THE INTERNET OF THINGS (IoT) FOR ENERGY EFFICIENCY IN BUILDINGS: A BIBLIOMETRIC REVIEW

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ABSTRACT: *Buildings are experiencing tremendous transformation, where Internet of things (IoT) is been used to transform traditional buildings into smart structures. While there are viable IoT techniques, developing IoT applications and operations to fully realise the technology's promise is needed. This may be done successfully by bridging the gaps in the present research to establish a foundation for future investigations. This study analysed extant literature in IoT (between 2008 and 2022) through a bibliometric review to tease out critical measures for their integration and transformation. The study adopted a science mapping quantitative literature review approach and employed bibliometric and visualisation techniques to systematically investigate data. The Scopus database was used to collect data and VOSviewer software to analyse the data collected to determine the strengths, weights, clusters, research trends in IoT. Important findings emerging from the study include recent literature by various researchers on IoT applications in buildings. The shift in recent patterns of research from developed to developing countries. Eighty-nine (89) keywords were analysed and divided into six clusters. Each cluster is discussed to present its research area and associated future studies in relation to Smart buildings. This paper uses bibliometric analysis to unpick recent trends in IoT and its relevant application to buildings. The paper provides a blueprint for future IoT research and practice, needed awareness and future strategy directions for IoT applications in construction. This creates opportunities to transition to more sustainable construction sector.*

KEYWORDS: *Bibliometric review, Energy efficient buildings, IOT (Internet of Things), Literature review, Smart buildings, sustainability, science mapping.*

1. INTRODUCTION

Massive challenges caused by rapid digitalization have greatly increased the demand for energy (Al-Obaidi et al., 2022). Energy consumption around the world is estimated to increase by 56% in 2040 (Energy Information Administration (EIA), 2013). Internationally, there are efforts to reduce energy consumption in buildings and cities such as the EU's 2050 roadmap which aims to lessen energy and gas emissions by approximately 40% (Fragkos et al., 2017). Buildings, both residential and commercial, have played critical roles in human existence by providing convenient, safe, and satisfying venues for emotional, physical, and social requirements. Building inhabitants should constantly feel secure and protected, since this might affect their general well-being and productivity (Lawal & Rafsanjani, 2022). As a result, real-time monitoring, control, and management of a building and its inhabitants, components, appliances, systems, environment, and health is critical (Rafsanjani et al., 2018; Ghahramani et al., 2020). This emphasizes the need of automation in both household and business settings. Smart buildings are unique structures that employ intelligent automation for their operations to provide efficient, pleasant, and secure environments for its users. Building automation utilizing the Internet of Things (IoT), a renowned advanced technology, can provide cutting-edge solutions for strengthening security and safety, remoting appliances/systems, monitoring occupants, increasing efficiency, and improving visual and thermal comfort (Kanan et al., 2018; Saha et al., 2018).

Although there have been various literature on IoT in the context of the buildings (Gholamzadehmi et al., 2020; Al-Obaidi et al., 2022; Wang et al., 2021; Bola et al., 2019; Mataloto, Ferreira & Cruz, 2019; Lawal & Rafsanjani, 2022), only few studies have sought to summarize the existing research using bibliometric techniques. For example, Gholamzadehmi et al. (2020) conducted a review of adaptive-predictive control strategy for heating ventilation and air conditioning (HVAC) systems in smart buildings. However, the scope of their study on smart buildings is focused solely on smart control of building energy services. Al-Obaidi et al. (2022) carried out a systematic review of IoT for energy efficient buildings and cities from a built environment perspective analyzing

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literature published between 2020-2022. However, their study scope is too broad and lacks exclusive statistical or quantitative focus on IoT research based on buildings. Bola et al. (2019) presented a critical survey of IoT based automated energy management in buildings. They reviewed various IoT applications in the area of building energy management and energy consumption data were recorded, which they highlight as a very important consideration in system planning and rehabilitation. Mataloto et al. (2019) presented efforts on optimizing energy consumption in buildings by use of an IoT based platform known as LoBEMS (Lora Building and energy management system). They developed an approach that helps local administration entities identify savings from personalized data visualization. Wang et al. (2021) conducted a thorough analysis of the extant literature on IoT and edge computing in different application fields, including smart homes and smart cities. Lastly, Lawal and Rafsanjani (2022) applied a systematic review while exploring the trends, benefits, risk and challenges of IoT implementation in residential and commercial buildings and highlighted that IoT is a crucial driver for the evolution of various types of buildings.

Even though each of these reviews provides a wealth of valuable insights, no thorough and timely review utilizing bibliometrics, focused solely on smart buildings can be found in the literature, which presents an important research gap. Since the academic literature in the field of IoT has had significant growth, the application of a quantitative review approach is required to better understand the knowledge structure of the field (Rivera & Pizam, 2015). Researchers should try to occasionally examine the accumulated body of knowledge as study fields develop and become more complex according to Ferreira et al. (2014), as well as understand new contributions, research trends and traditions, topics being studied and investigative the structure of knowledge and future research directions.

This study analyses extant literature in IOT and its application to buildings (between 2008 to 2022) through a bibliometric review, to tease out critical measures for their integration and transformation. The objectives are to evaluate the global research trends of IOT application in construction based on citation analysis of countries and co-occurrences analysis of author keywords cluster, using Vosviewer document analytic software and Scopus database. The study findings would benefit the academic community as it contributes to (1) providing valuable directions by examining the bibliometric status of IOT in the built environment sector from the existing literature, identifying the knowledge areas with links for their integration and (2) identifying the critical areas needed to advance IOT application in buildings in future studies and to support practical implementation.

2. METHODOLOGY

Researchers commonly employ three approaches to evaluate literature, according to Zupic and Cater (2015): (1) a qualitative approach of a systematic literature review, (2) a quantitative approach via meta-analysis, and (3) science mapping (based on the quantitative approach utilizing bibliometric methodologies). The third technique is viewed as the most suited for assessing the state-of-the-art literature of a research topic and is quickly becoming increasingly popular in numerous disciplines of study (Tavares-Lehmann & Varum, 2021). Science mapping uses bibliometric approaches such as citation analysis to assist academics in identifying trends in the structure and dynamics of scientific subject topics. Using the bibliometric approach in scientific literature reviews enhances rigor and lowers researcher bias (Cavalieri et al., 2021). It is superior to typical literature reviews in that it provides for a more objective and methodical selection and assessment of scientific research on a specific topic (Cobo et al., 2015). To fulfil the study's goals and objectives, we used a bibliometric technique that includes three stages of review: (1) data collecting, (2) analysis and visualization, and (3) interpretation, like a prior study by (Obi et al., 2023).

2.1 Data collection

A search query, selection of relevant database(s), and data screening are all part of the data collecting process (Ari & Cuccurullo, 2017). Employing the correct search phrases in a bibliometric study is important to success (Obi et al., 2023). According to Lawal and Rafsanjani (2022) we followed the search terms for IOT application in buildings. They chose keywords for the IOT research after conducting a thorough review of earlier relevant studies on the definition and application of IOT in various kinds of residential and commercial buildings and they compiled a list of important terms that are used interchangeably. As a result, a mixture of appropriate search phrases was employed, and the whole search code is as follows:

“IOT buildings” OR “Internet of Things buildings” OR “smart buildings” OR “Intelligent Buildings” OR “automated buildings”.

We identified a database that contained bibliometric data. Scopus and Web of Science (WoS) are now prominent databases for retrieving publications (Obi et al., 2023). The Scopus database was used to extract and collect bibliographic data for the study. Scopus is a digital bibliographic platform widely recognized for high quality standards and a frequent instrument for doing construction-related bibliometric research (Patel et al.,2021). Rani and Kumar (2022) conducted bibliographic analyses and identified Scopus as a favored alternative for IOT application review research. Similarly, recent literature reviews in IOT research (Lawal & Rafsanjani, 2022; Al-Obaidi et al., 2022) have employed the Scopus database.

To screen the obtained data, we used a set of inclusion and exclusion criteria (relevance, language, and quality). A total of 26,512 papers were returned because of the search in the Scopus core collection. The publication period was limited to 2008 to present (2022) and was chosen because the classification by year of publication shows a growing trend of articles published in relation to IOT within this period. **Figure 1** shows distribution of articles by year of publication. From this image it can be said that publication on IoT related to building applications picked up in 2005 and had a more significant number of publications from the year 2008. The year 2008 recorded 52 articles whilst the subsequent years recorded a rise in the number of articles published progressively and considering the increasing number of articles over the years, with the constant rise in publications, it can be inferred that literature on IOT application will continue to increase in years to come.

Finally, Papers from subject areas with no strong affiliation to application of IoT in buildings like chemistry and decision sciences were eliminated. Non-English publications in the relevant topic areas were removed to avoid translation difficulties and to decrease ambiguity in essential ideas. Associated keywords presented by Scopus because of searching for relevant documents were skimmed through to identify duplicates and words with no strong link to the research area were subsequently excluded. To ensure the quality of the papers utilized, only peer-reviewed article publications and reviews were included. After that, the author performed further skim readings of the title, abstract, and selected document, resulting in the elimination of papers not connected to IOT application in buildings. Applying the relevance, language and quality criteria resulted to 21,637 papers being deleted during the process, leaving 4,875 articles used for the analysis. These articles were then exported to excel from Scopus (in the order of most cited to least cited documents) to allow the implementation of an analysis software (VOSviewer).

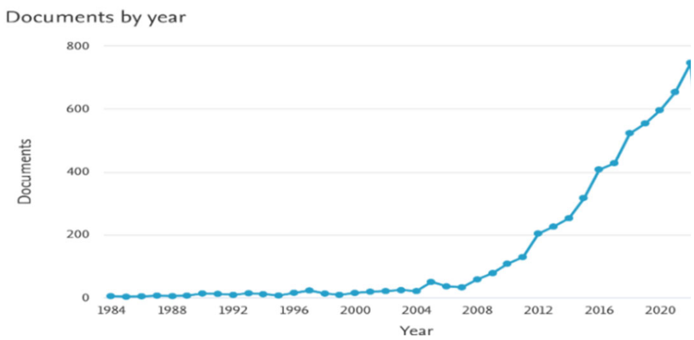

Fig. 1: Showing a growing trend of research on IoT application to construction. (Source: scopus).

2.2 Data analysis and visualization

This paper makes use of citation and co-occurrence analysis. Commonly used bibliometric methodologies, according to Mas-Tur et al. (2021), are:

(1) Co-occurrence analysis which evaluates the conceptual structure of knowledge in the subject, finding relevant keywords and themes related with the primary concepts of research.

(2) Citation analysis estimates the impact of publications, authors, journals, or nations based on citation rates.

The bibliographic information was presented using the visualization of similarities (VOS) viewer software version 1.6.19. VOSviewer allows you to map, visualize, and identify the network structure in research (Leydesdorff & Nerghes, 2017). Because of the ease of understanding, presentation, and visualization of the maps, it was chosen above other regularly used tools such as Pajek and Citespace. The network is composed of distance-based maps, with the distance between two elements reflecting the intensity of their link. A shorter duration often suggests a stronger bond. The size of the item label reflects the number of instances of the phrase discovered. A bigger label size indicates that the related item appears in more publications, while various colours reflect distinct groupings of items aggregated by VOSviewer's clustering approach (Yin et al., 2019).

3. RESULT AND DISCUSSION DATA ANALYSIS AND VISUALISATION

This section presents the bibliometric and network analysis results as tables and networks and a discussion of the various results gotten from the analysis.

3.1 Citation analysis

Citation analysis is used to identify high-impact journals and significant nations in IoT research. The number of publications and citations are used to assess the influence and quality of research in a certain topic (Wuni et al., 2020).

3.1.1 Countries involved in researching the application of IoT in construction.

The minimal number of citations and publications was set at 10 and 5 respectively, using VOSviewer. This was done to guarantee that only nations that are actively engaged in research on IOT application for buildings are chosen. 72 out of the 160 nations available were chosen to meet the criteria; the findings of the analysis are shown in **Figure 2**. There are 10 most productive countries leading in research on IoT in relation to building applications. The republic of China with a total of 730 documents and 35,390 citations. It is followed by United States of America with a total of 716 documents as well as other nations within the top ten as shown in **Table 1.** Among the ten nations China and India are the only developing countries, which is similar to results gotten in a review study by (Al-Obaidi et al., 2022).

Table 1: Top 10 most productive countries involved in the research of IoT application to building construction.

Country	**Document**	**Citation**
China	730	35,390
United States of America	716	21,163
United Kingdom	323	14,280
Italy	260	11,550
South Korea	226	8,480
India	225	6,343
Canada	195	10,701
Australia	182	6,612
Spain	164	5,942
Germany	156	6,450

The closer the colour is too yellow, the recent the investigation is in literature, as seen in **Figure 2,** from countries like United States, Morocco, Nigeria and Pakistan. This demonstrates that recent study patterns are majorly researched by developed nations but are also shifting towards developing countries, particularly those seeking sustainable and energy efficient improvements in their building industry, highlighting the need for more empirical research in these developing countries.

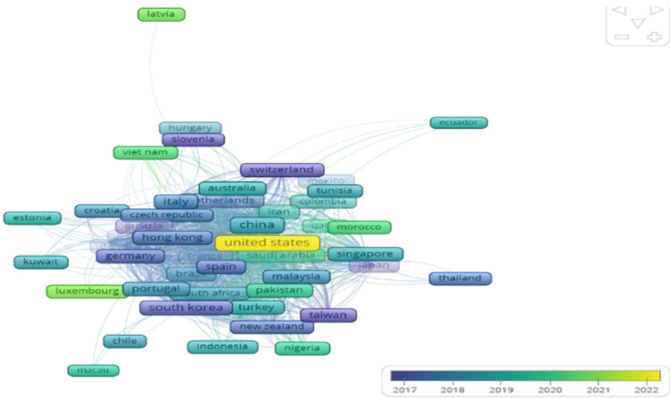

Fig. 2: Vosviewer map of countries associated with the application of IoT in construction.

3.2 Co-occurrence analysis on IoT application in construction

Co-occurrence, highlights keywords and have an important role in bibliometric analysis. According to Van Eck and Waltman (2014), author keywords should be used for bibliometric analysis to show patterns in current research. As a result, author keywords were chosen as the foundation for the current study's co-occurrence maps. The threshold of occurrences of a keyword was chosen at 15 based on recent bibliometric literature review (Baghalzadeh Shishehgarkhaneh et al., 2022). Repeated terms (for example ("smart house" and "smart homes") were eliminated. The criteria for the study were fulfilled by 89 of the 10,008 keywords. The co-occurrence network's large nodes (frames) and colour presentations, as well as the primary linkages, were investigated to analyse the research hotspots and concerns dominating IoT literature. The cluster formation was used in the co-occurrence analysis.

3.2.1 Co-occurrence of author keyword by cluster

The keywords "Smart buildings", "Energy efficiency" and "Internet of Things" have large nodes in the network as seen in **Figure 3**, indicating researchers have been more interested in studying these areas of research and their similar concepts. Six clusters, as shown in **Figure 3** emerge following the analysis.

Cluster 1 (IoT based sustainable construction design): It is in red and the largest cluster with 28 items: building energy efficiency, green building, building information model, thermal energy storage, solar energy are some of the relevant keywords in this cluster. This cluster indicated a strong focus on sustainable construction design in relation to IOT application to buildings. From a design perspective extensive IoT research has focused on Building energy efficiency, especially due to this area of research been one of the main goals of construction design (Lawal & Rafsanjani, 2022).

Cluster 2 (Building automation system): It is green with 17 items; building energy management system, anomaly detection, building automation, model predictive control, building control, hvac, indoor air quality and thermal comfort are some of the relevant keywords emerging from this cluster. This cluster is concerned with IoT based building automation systems and the efficient control and management of building energy services.

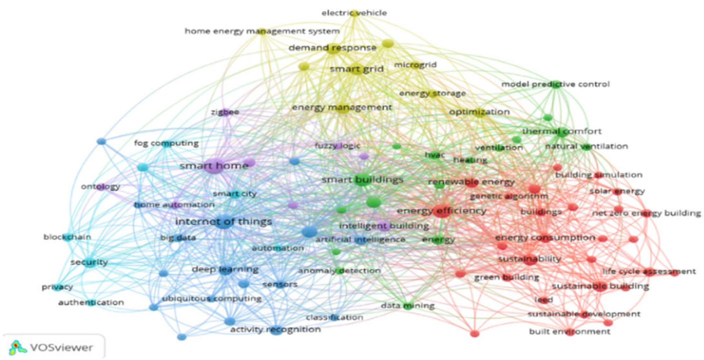

Fig. 3: keyword network visualization by cluster

Cluster 3 (AI in smart buildings): It is in blue and is made up of 17 items: machine learning, sensors, AI (artificial intelligence), internet of things, activity recognition, ambient intelligence, big data are some relevant keywords from this cluster. This cluster highlights the core operational principles of IoT, it explores the concept of AI and its contribution to the realisation of smart buildings.

Cluster 4 (IoT for efficient energy management in buildings); It is yellow and includes 10 items; Energy management, demand response, smart grid, micro grid and home energy management system are some of the relevant keywords. This cluster highlights various technical functions of an IoT system to efficiently manage energy consumption in buildings.

Cluster 5 (Improved quality-of-service in smart buildings); It is purple and includes 9 items; wireless sensor network, neural network and Interoperability are some of the relevant keywords in this cluster. This cluster highlights the improved quality-of-service offered by IoT networks to smart building occupants or smart users.

Cluster 6 (Blockchain in smart buildings); It is light blue in colour and includes 8 items; authentication, blockchain, smart city, privacy and security are some of the relevant keywords in this cluster. This cluster is centered around the use of blockchain in IoT based smart building systems and the role of the technology in protecting user privacy and safeguarding information that flows through IoT devices or nodes.

4. DISCUSSION OF CLUSTERS AND FUTURE RESEARCH DIRECTION

In this section, the six study fields (Blockchain in smart buildings, AI in smart buildings, IoT for efficient energy management, Improved quality-of-service in smart buildings, building automation and IoT based sustainable construction design) emerging from the results of the co-occurrence cluster analysis are discussed. The knowledge gaps and future study directions are also highlighted.

4.1 Blockchain in smart buildings

Blockchain is an emerging concept in IoT based technology with strong links to smart buildings and smart cities. Blockchain has emerged as an important layer of trust (Siountri et al., 2020). as well as a novel approach for improving data integrity and privacy in smart buildings. Blockchain, a type of distributed ledger, can be utilized to reduce the challenges of information sharing and security in smart buildings (Rejeb et al., 2022). Unlike traditional databases, blockchain is built on a peer-to-peer network design in which all network users handle transactions effectively and flexibly rather than being controlled by a trusted centralized authority (Nguyen et al., 2020). It is conceivable to construct and update smart networks in the future, strengthen their resilience, and safeguard a rising amount and diversity of services by relying on blockchain's decentralization, immutability, and accountability. In this regard, blockchain has the potential to address important security concerns while also facilitating smart city operations (Rejeb et al., 2021). Machine learning is utilised to extract vital information from outsourced data and the findings are then stored securely on the blockchain to ease sharing (Rejeb et al., 2022).

The overall effect of blockchain and IoT can be improved with the introduction of 5G. Blockchain technology provides numerous answers to the issues posed by 5G networks. According to Azzaoui et al. (2020), the technology supports AI-powered 5G and leads to the development of a more efficient, and secure cellular network. As a result, 5G will serve as a foundation for IoT, blockchain and mobile edge computing (MEC), enhancing the analysis, collection and exploitation of smart building data (Hemmings, 2020) and making bandwidth less of a limiting factor in overall ecosystem design. With the transition to 5G networks, there is increased interest in investigating the pending issues of a 5G-enabled IoT for blockchain-based smart building applications, as 5G cellular networks are ineffective due to increasingly complex configuration issues in clouds and systems lacking AI functionality (Chen et al., 2020). As a result, future research should look at how blockchain might affect critical elements of IoT-based smart building applications (Rejeb et al., 2022).

4.2 AI in smart buildings

Artificial intelligence (AI) is another key area in IoT systems with strong links to smart buildings. The transition to smart buildings necessitates the collaboration of several technologies to make inhabitants' lives more convenient and inclusive (Ahad et al., 2020). AI is regarded as a critical tool for advancing urban sustainability and building more inclusive and secure settings, as supported by the United Nations' Sustainable Development Goal 11 (Sustainable development goal (SDG), 2015). AI systems rely on massive amounts of data and employ learning algorithms to discover patterns in the data, allowing for event prediction and decision-making tasks (Hariri et al., 2019). This is especially essential when combined with other developing technologies that increase efficiency by automating data collecting and eliminating the need for trusted third parties, hence maximizing profitability Hariri et al., 2019). In the work of Awan et al. (2020), for example, machine learning algorithms used to estimate parking spot availability in smart commercial buildings are thought to benefit from data collected by IoT sensors and devices.

Future research into this cluster may focus on how urban decision-makers might collaborate with residents to develop and create smart cities that meet their expectations. The subject of how to involve all stakeholders in a solution-oriented and citizen-centric manner while solving urban difficulties with IoT and AI approaches is of greater relevance (Brynskov, 2018). Empirical research is also required to better understand the stakeholder-related issues that enable or impede IoT and AI implementation in smart construction (Rejeb et al., 2022).

4.3 IoT for efficient energy management in buildings

Energy management is an empirical function of smart buildings with strong links IoT application to construction. The associated cluster describes how energy management in relation to IoT technology is gaining attention, with numerous sophisticated and ubiquitous smart construction applications, such as smart grids. Smart grids are modern power networks that can change and re-adjust dynamically to offer electricity at a cheap cost and high quality (Alsamhi et al., 2019). Since IoT applications consume a significant amount of energy, smart building solutions must be able to use energy more effectively and implement effective energy prediction systems that reflect the dynamics of the IoT environment (Luo et al., 2019).

The smart grid enables the exchange of energy and information between customers and utilities. Yet, the complexity of utilities to handling real-time data for making business-critical choices remains a difficulty (Alsamhi et al., 2019). Increased data usage improves grid stability and performance while also allowing the utility provider to make better decisions, allowing for efficient demand-side management and demand response. Nevertheless, the massive amount of raw data is incomprehensible or useless without a dependable and consistent capacity to process, analyse, and comprehend the information contained within such a massive amount of data. As a result, before taking action based on the data, the data must be turned into useable information. Such transformation is a difficult procedure since helpful information is not readily apparent from the data. Therefore, further investigation on the challenges faced by utilities to handle real-time data is essential (Syed et al., 2021).

4.4 Improved quality-of-service in smart buildings

Wireless sensor network (WSN) represents an important component of IoT by promoting resource efficiency and increasing smart inhabitants' quality of life (AlSawafi et al., 2020). WSN can handle large-scale installations in any metropolitan setting to perform tasks including real-time monitoring of physical and environmental conditions, routing and load balancing, industrial process monitoring, and energy efficiency optimization (Alsamhi et al., 2019). Researchers have previously focused on WSN-based smart building and city applications for scheduling and routing (e.g., smart grids) that take into consideration the energy efficiency and quality of service (QoS) (Faheem et al., 2019). Nonetheless, the mobility and changing network topologies of IoT nodes continue to pose challenges to the stringent fulfilment of QoS requirements in IoT-based smart building applications. As a result, future research must adapt current routing algorithms in WSN to give QoS guarantee in terms of latency, dependability, bandwidth usage, scalability, and throughput. Moreover, researchers must investigate low-cost methods of connecting IoT equipment and collecting data across the vast number of decentralised WSN in smart cities (Sobin, 2020).

4.5 IoT based sustainable construction design

Building energy efficiency is another key area with strong link to IoTs application to buildings. According to recent studies, tracking energy use in buildings has piqued the interest of many academics interested in IoT and energy saving measures (Xu et al., 2020). Furthermore, the drive towards combining smart buildings with cutting-edge detection techniques has begun to set the framework for seeing IoT as an essential component of smart cities (Al-Obaidi et al., 2022). Recent research has revealed a surge in interest in IoT applications in smart buildings to enhance energy efficiency and decrease environmental concerns. According to other research, if buildings consider effective communication between their systems for operation, they can save a significant amount of energy. As a result of advancements in networking, computing, and sensing technologies, IoT has emerged as a critical component in the design and operation of any smart item in the built (Kumar et al., 2022).

Smart design, smart action, smart control, smart monitoring, smart energy, smart waste and smart water are essential features of an IoT residential/commercial building that should be considered while converting a building to a smart one to make the atmosphere more comfortable not only for the residents but also for the management staff (Lawal & Rafsanjani, 2022).These features necessitate many types of data, and thus the key difficulty might be big data analytics, which arises from the huge, diversified, and time-evolving high-resolution data provided by IoT devices and sensors. The growth of technology has resulted in a dramatic increase in the number of connected IoT devices, resulting in massive data generation and transfer. To improve data flow between devices many different technologies are necessary, which raises the complexity of IoT systems in every kind and size of residential or commercial structure. Based on our analysis of the literature, smart waste and water have seldom been investigated and so additional future research into these aspects is advised to create a completely automated building (Lawal & Rafsanjani, 2022). Furthermore, IoT device batteries consume a large amount of energy and as a result, the rising rate of IoT device deployment has resulted in increased energy consumption making IoT and environmental concern which should be considered in future research (Lawal & Rafsanjani, 2022).

4.6 Buildings automation system

Building automation is yet another integral part of IoTs application to building with strong links to the research area. A building automation control system (BACS) is defined as a computer-based and automated system that analyses the specific needs of a building by controlling the associated mechanical and electrical plants/equipment installed in the building, thereby contributing to energy savings without compromising user thermal/visual comfort. A BACS's major goal is to maintain occupant thermal/visual comfort while maintaining an energy efficient and cost-effective building operation. It incorporates algorithms that replace user demands in directing technological systems depending on various objectives, such as; thermal comfort, Energy savings and cost savings (Gholamzadehmir et al., 2020).

The use of model predictive control, which also has a direct link to IoT application in buildings is a technique in BACS which has recently attracted a lot of interest from the scholarly community (Serale et al., 2018). An advanced control strategy (ACS) with a forecasting function, known as MPC, is necessary to achieve high energy and comfort performance levels by including renewable energy generation, innovative solutions for technical systems (e.g., heat pumps), and energy storage systems (Gholamzadehmir et al., 2020). MPC is commonly used in the building industry to forecast the dynamic behavior of systems in the future and alter reaction by the controller, accordingly, resulting in energy and cost savings while maintaining thermal comfort (Serale et al., 2018).

The evaluation of an accurate prediction horizon based on the system's characteristics is one of the fundamental concerns in predictive control systems (Gholamzadehmir et al., 2020). According to the literature study, the most typical setting for prediction and horizon control is one day ahead (Liu & Heiselberg, 2019). Nevertheless, the tuning of the prediction and control horizons may be influenced by the building boundary circumstances, such as the climate environment and building characteristics (Gholamzadehmir et al., 2020). There is particularly limited data on the link between the prediction horizon and control horizon. As a result, additional research is needed to analyse the relationship between prediction/control horizon and various building boundary conditions for best energy and cost saving outcomes. Because the predictive model is dependent on the quality of the input data, the function of sensor reliability and location are critical. There are just a few publications that report on this crucial issue and therefore research is required to fill this vacuum, which would otherwise be a weak spot for ACS (Gholamzadehmir et al., 2020).

Based on the study findings as discussed, predominant and emerging concepts that can serve as conduits for IoTs application in Buildings and the proposed directions for advancing research and practice are summarized in **Table 2**. Future investigations could pay more attention to the current and emerging concepts in IoT and its application to buildings.

Table 2: Themes, research area and future research direction

Theme	Research areas and concepts with links to IoT application in Buildings	Future research direction

Blockchain in IoT based smart buildings	Blockchain Privacy Smart city Security	Issues of a 5G-enabled IoT for blockchain-based smart building. applications Cost-effective and scalable blockchain solutions.
AI in smart buildings	Machine learning AI Sensors Activity recognition Ambient intelligence	Stakeholder-related issues that enable or impede IoT and AI implementation in smart buildings. How to involve all stakeholders in a solution-oriented and citizen-centric manner while solving urban difficulties with IoT and AI approaches
IoT for efficient energy management	Energy management Smart grid Micro grid Demand response Home energy management system	The complexity of utilities to handling real-time data for making business-critical choices
Improved quality-of-service in smart buildings	Wireless sensor networks Interoperability Neural network	Adapt current routing algorithms in WSN to give QoS guarantee in terms of latency, dependability, bandwidth usage, scalability, and throughput. low-cost methods of connecting IoT equipment and collecting data across the vast number of decentralised WSN in smart cities.
IoT based sustainable construction design	Building energy Efficiency Building Information Model Building envelope Green building Thermal energy storage Solar energy Sustainability	Investigation on smart waste and smart water Negative effects of IoT as an environmental concern
Building automation system	Building energy management system Anomaly detection	Analyse the relationship between prediction/control horizon and various building boundary conditions for best energy and cost saving outcomes

	Building automation Model predictive control Building control Hvac Indoor air quality thermal comfort	Reliability and proper location of IoT Sensors.

5. CONCLUSION

This study conducts a bibliometric review of the extant literature on IoT application in construction from 2008 to 2023 to tease out critical measures for its integration and transformation. In this study, 4875 publications on IoT within the building and construction sector retrieved from Scopus were analyzed using bibliometrics and network analysis in VOSviewer.

The demographic maturity levels and increased prevalence are most notably from China, Italy, the USA and UK Nevertheless, trends in recent IoT research are emerging from developing countries, indicating a surge for sustainable improvements in their construction practices. To enhance IoT research globally, developed and developing countries need to collaborate. The poor collaborative links between IoT researchers across developed and developing countries may be one of the reasons contributing to the slow understanding and uptake of IoT systems in developing economies. Therefore, funding research projects, research hubs and spoke networks and other collaborative research activities as appropriate between developed and developing countries should be highly encouraged. These can facilitate knowledge exchange and transfer on policies and implementation strategies to promote IoT application practice in construction.

Six cluster areas were identified including blockchain in smart buildings, IoT based sustainable construction design, Improved quality-of-service in smart buildings, building automation system, IoT for efficient energy management in buildings and AI in smart buildings. These areas currently seek to optimize energy efficiency in buildings, reduce waste and the environmental impact throughout a building's operation. There are emerging concepts from the cluster and there is the need to expound their links, especially block chain. This is with the view of foreseeing a more strategic approach for improving data integrity and privacy in smart buildings and cities.

This study contributed by highlighting the bibliometric research status of IoT in relation to its application in buildings, identified current gaps in the literature and provided directions for future studies and practice. More importantly, the evidence gleaned from this study would help IoT players and policymakers to develop bespoke strategies, frameworks and policy measures for integrating and implementing IoT practices, creating opportunities to transition to more sustainable systems in the construction sector. However, there were some limitations. One is the use of only Scopus database. Second is the use of only Journal articles and reviews written in English, and third is the exclusion of discussions of other emerging areas because they had no current links to IoT. Future research may use other databases or incorporate data from different sources to enhance generalizability. They can also broaden the sources of documents such as books and include those in foreign languages, to broaden the variety of data. Future research might investigate additional growing sectors where there are presently no linkages to IoT. In addition, expert systems and fuzzy tools can be used to explore a more in-depth quantitative analysis.

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